First Results from the Online Radiation Dose Monitoring System in ATLAS Experiment

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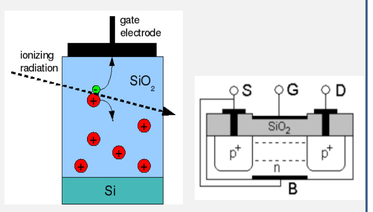
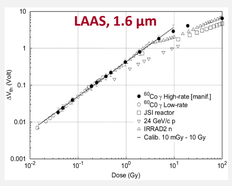
- detectors and electronics in ATLAS experiment will be exposed to large doses of radiation: **TID > 100 kGy**, **$\Phi_{eq} > 10^{14}$ n/cm²**
- online Radiation dose monitoring system measures accumulated ionizing dose in SiO_2, displacement damage in silicon and fluences of thermal neutrons.
- continuous monitoring of doses necessary to understand performance of the detector
- doses are monitored at 14 locations in the Inner Detector and at 48 locations at larger radii
- sensors are read out every 60 minutes and readings are stored in the database.

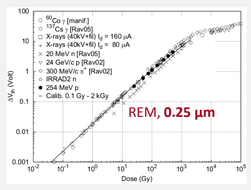
➔ results of dose measurements after 2 years of ATLAS data taking are presented

TID measurements with RadFETs

- RadFETs: p-MOS transistor
- holes caused by radiation get trapped in the gate oxide:
  ➔ increase of threshold voltage with dose: $\Delta V = a \times (TID)^b$
- sensitivity and dynamic range depend on oxide thickness:







Inner detector:
- 3 RadFETs at each monitoring location: LAAS 1.6 µm; REM 0.25 µm; REM 0.13 µm

Other locations (lower doses):
- LAAS 1.6 µm

Radfet calibration curves (F. Ravotti ,PhD thesis, CERN-THESIS-2007-013)

NIEL measurements with diodes

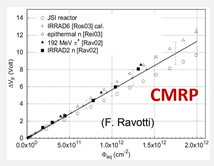
- hadrons cause bulk damage in silicon consequence: increased resistance, reduction of carrier lifetime, increase of reverse current
  ➔ forward bias: voltage at given forward current increases
  ➔ reverse bias: increase reverse current

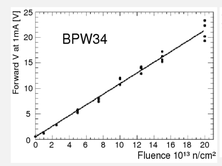
Forward bias

- linear response $\Delta V = k \cdot \Phi_{eq}$
- high sensitivity diode (CMRP, University of Wollongong, AU) 10^9 to ~10^{12} n/cm²,
- commercial silicon PIN photodiode BPW34F 10^{12} to ~10^{15} n/cm²

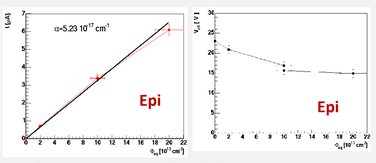
Reverse bias

- reverse current proportional to fluence $I = \Phi_{eq}/\alpha V$
- **25 µm** x 0.5 cm x 0.5 cm pad diode with guard ring structure processed on epitaxial silicon ➔ **thin epitaxial** diode can be depleted with V_{bias} < 30 V also after irradiation with 10^{15} n/cm²





Calibration curves (forward bias)

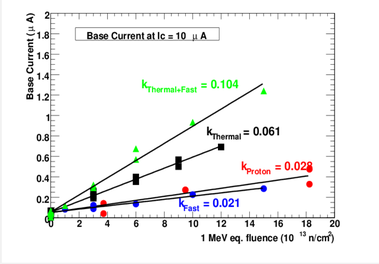


Reverse current and depletion voltage vs. fluence

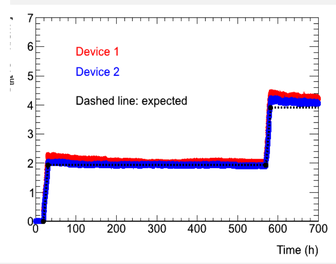
Thermal neutrons

- bipolar transistors (DMILL) used in front end ASICs
- measure base current at given collector current
  ➔ monitor status of front end electronics
  ➔ sensitive to fast and thermal neutrons

$\Delta I_b/I_c = k_{eq} \cdot \Phi_{eq} + k_{th} \cdot \Phi_{th}$; k_{eq}, k_{th} and Φ_{eq} known
→ Φ_{th} can be determined



Base current increase after irradiation with fast hadrons, thermal neutrons and mixture of thermal and fast neutrons (reactor)

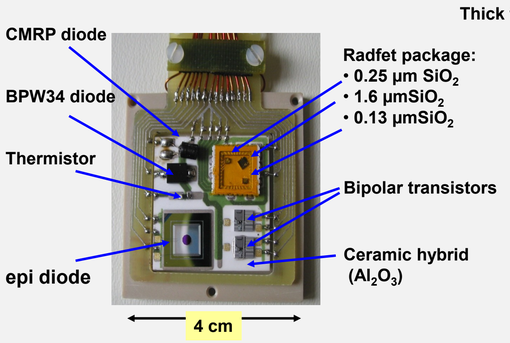


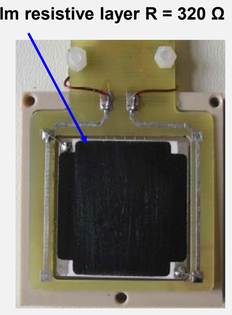
Response of DMILL transistors to thermal neutrons in reactor

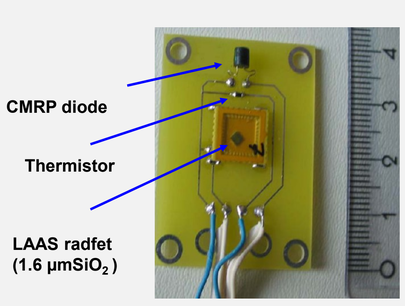
Radiation Monitor Sensor Board (RMSB)

Inner Detector

- for dose monitoring in the Inner Detector:
  - large range of doses
  - no access in 10 years
  ➔ **need many sensors**
- large temperature variations (-10 to 20°C) at some locations
  ➔ stabilize temperature to 20 ± 1 °C by heating back side of the ceramic hybrid





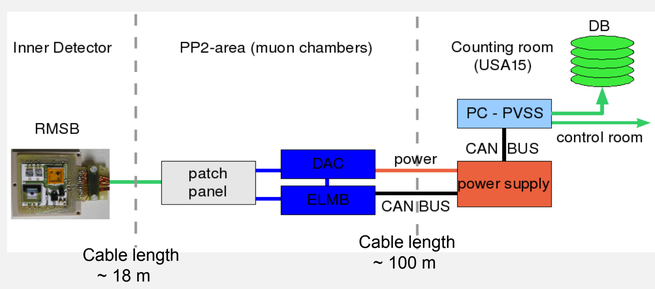


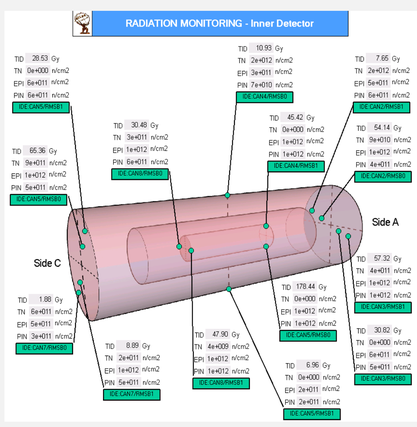
Caloriemeters, Muon detectors

- lower dose ranges
  ➔ cGy to 10 Gy, 10^9 to ~10^{12} n/cm²
- no temperature stabilization
  ➔ correct read out values with known temperature dependences

Readout

- use standard ATLAS Detector Control System components
  - **ELMB:**
    - 64 ADC channels
    - can bus communication
  - **ELMB-DAC:**
    - current source, 16 channels (I_{max} = 20 mA, U_{max} = 30 V)
- sensors are biased only during readout (~ few minutes every hour)
- software written in PVSS



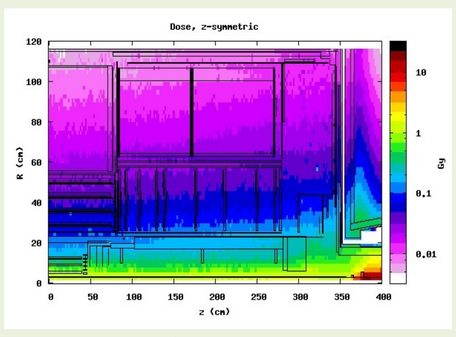


Screen displaying accumulated doses in the Inner Detector

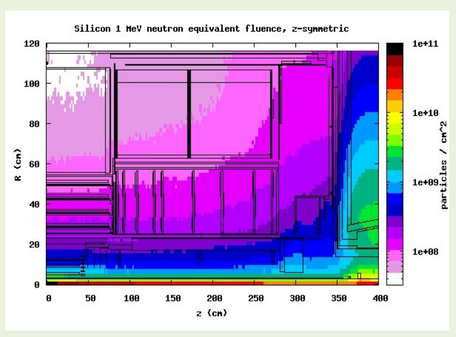
Fluka simulations

Radiation backgrounds have been simulated in the ID using the

- FLUKA particle transport code
- PHOJET event generator
- simulations done for $\sqrt{s}$ = 7 TeV assuming a proton-proton inelastic cross section 77.5 mb as predicted by PHOJET
- ionizing dose in SiO_2 and displacement damage in silicon calculated from simulated particle fluxes
- predictions of doses in Gy and fluences of 1 MeV equivalent neutrons normalized to unit of integrated luminosity



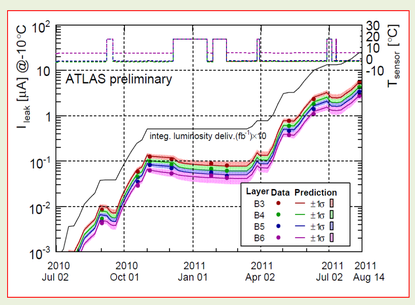
Dose per pb^{-1} integrated luminosity



1 MeV equivalent fluence per pb^{-1}

Doses and fluences per fb^{-1} of integrated luminosity			
Location	Coordinates	Dose (Gy)	1 MeV equivalent neutron fluence (10^{11} n/cm^{-2})
Pixel support tube	r= 23 cm |z| = 90 cm	110	2.22
Inner Detector End Plate – small radius	r = 54 cm |z| = 345 cm	55.4	2.24
Inner Detector End Plate - large radius	r = 80 cm |z| = 345 cm	27.0	1.35
Cryostat Wall	r = 110 cm |z| = 0 cm	4.9	0.45

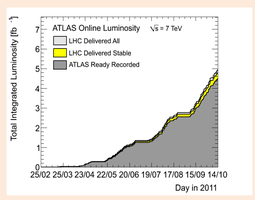
Simulated curves

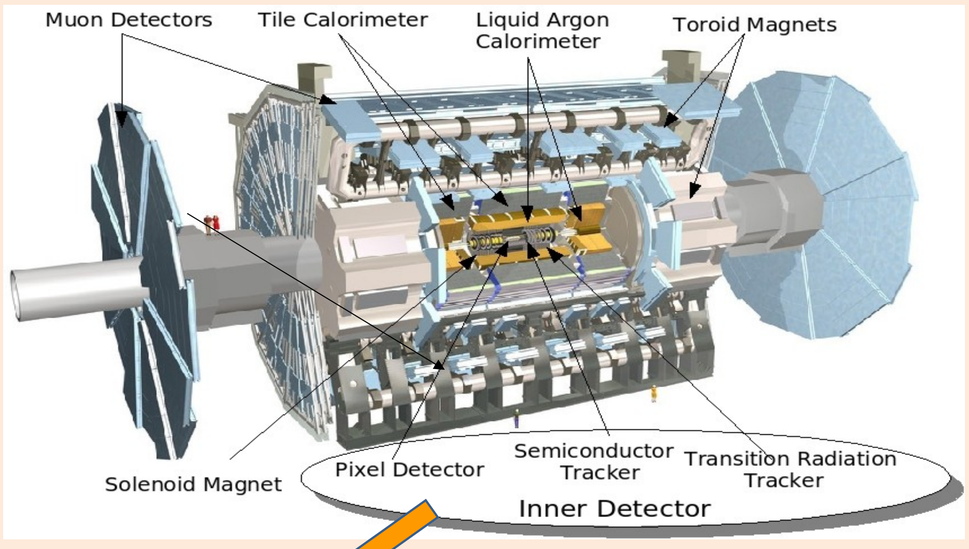


Leakage current in silicon strip detectors in ATLAS SCT increases because of radiation damage.
Good agreement between measurements and predictions from Fluka simulation!

RESULTS

Data up to 20th September 2011
Integrated luminosity ~ 3.4 fm^{-1}

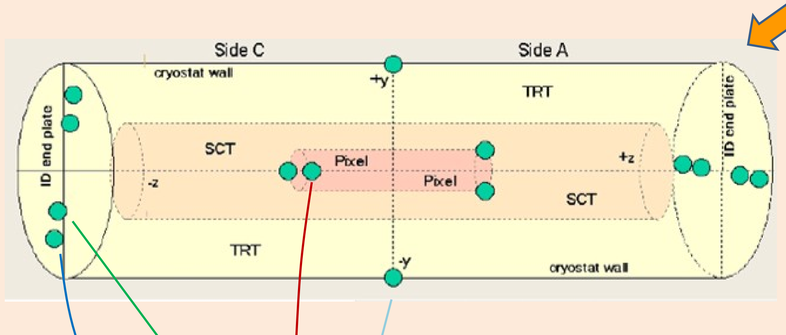


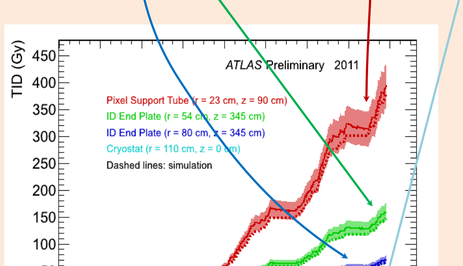


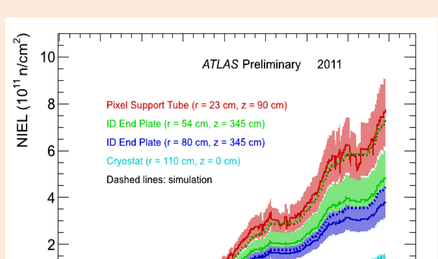
Inner detector

14 monitoring locations in the Inner Detector:

- 4 on Pixel Support Tube (r = 23 cm, |z| = 90 cm)
- 4 on ID end plate small radius (r = 54 cm, |z| = 345 cm)
- 4 on ID end plate large radius (r = 80 cm, |z| = 345 cm)
- 2 on Cryostat wall (r = 100 cm, z = 0)

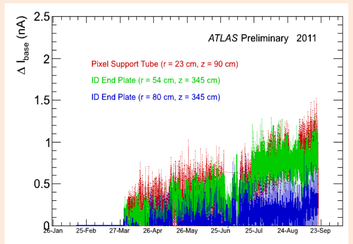


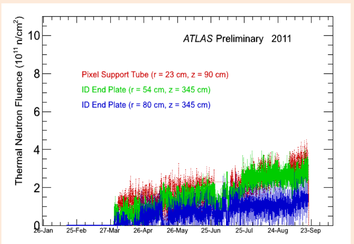




Plots show averages for sensors at same location type

Very good agreement between measurements and simulation!

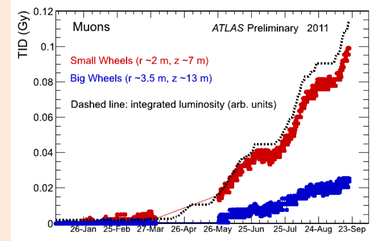




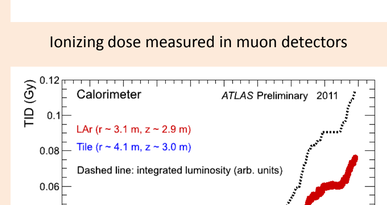
Base current increase in bipolar transistors → Thermal neutron fluence

Outside of inner detector

- 48 monitoring locations in muon detectors, calorimeters and on PP2
  - 16 in muon detectors
  - 22 in calorimeters
  - 10 near electronics on patch panel 2 (r ~ 5.2 m)
- doses on the limit of sensitivity:
  TID < 0.1 Gy, NIEL < 1e10 n/cm²



Ionizing dose measured in muon detectors



Ionizing dose measured in calorimeters

➔ **dose increase proportional to integrated luminosity**